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AD-A206 857

IDA MEMORANDUM REPORT M-520

EXPOSURE OF ICBM AND SLBM TRAJECTORIES TO SUNLIGHT

Thomas S. Paterson

January 1989

Prepared for
Strategic Defense Initiative Organization

IDA
INSTITUTE FOR DEFENSE ANALYSES
1801 N. Beauregard Street, Alexandria, Virginia 22311-1772

IDA Log No. HQ 88-33788

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY
N/A

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE
N/A

3. DISTRIBUTION/AVAILABILITY OF REPORT
Approved for public release; distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S)
IDA Memorandum Report M-520

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION
Institute for Defense Analyses

6b. OFFICE SYMBOL (If applicable)

7a. NAME OF MONITORING ORGANIZATION
DoD-IDA Management Office, OUSD(A)

6c. ADDRESS (City, State, and Zip Code)
1801 N. Beauregard Street
Alexandria, VA 22311

7b. ADDRESS (CITY, STATE, AND ZIP CODE)
1801 N. Beauregard Street
Alexandria, VA 22311

8a. NAME OF FUNDING/SPONSORING ORGANIZATION
Strategic Defense Initiative Organization

8b. OFFICE SYMBOL (If applicable)

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
MDA 903 84 C 0031

8c. ADDRESS (City, State, and Zip Code)
The Pentagon
Washington, DC 20301-7100

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
		T-R2-261 (3a)	

11. TITLE (Include Security Classification)
Exposure of ICBM and SLBM Trajectories to Sunlight

12. PERSONAL AUTHOR(S).
Thomas S. Paterson

13. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 8/88 TO 12/88	January 1989	18

16. SUPPLEMENTARY NOTATION

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
tracking, discrimination, sunlight, visible, sensor

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Due to the cost and complexity of infrared and radar sensors, visible sensors could be a useful alternative for strategic defense surveillance systems, provided the threat is exposed to sunlight for a significant portion of its trajectory. This paper examines the exposure of ballistic missile trajectories to sunlight as a function of solar latitude (time of year) and launch time. Nine representative trajectories were chosen to illustrate the effects of range, apogee, and maximum latitude on sunlight exposure. It was found that certain Soviet-to-CONUS trajectories would be completely in the Earth's shadow only when launched during a brief time window on or near the winter solstice. Certain SLBM trajectories had full-shadow launch windows from late fall to early spring. However, trajectories representing those of SS-18's flew very close to the pole, exposing most of their paths to sunlight regardless of launch time or solar latitude. Weighting the trajectories to represent aggregates of a Soviet spike attack, at least 69 percent of the threat was exposed to sunlight for at least 500 seconds on the winter solstice, and at least 95 percent was exposed on the spring/fall equinoxes. These percentages exceed the JCS requirements of a Phase One Strategic Defense System, particularly because of the susceptibility of SS-18 trajectories to sunlight exposure.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT
☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL
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22c. OFFICE SYMBOL

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted.
All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

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Contract MDA 903 84 C 0031
Task T-R2-261(3a)

ABSTRACT

Due to the cost and complexity of infrared and radar sensors, visible sensors could be a useful alternative for strategic defense surveillance systems, provided the threat is exposed to sunlight for a significant portion of its trajectory. This paper examines the exposure of ballistic missile trajectories to sunlight as a function of solar latitude (time of year) and launch time. Nine representative trajectories were chosen to illustrate the effects of range, apogee, and maximum latitude on sunlight exposure. It was found that certain Soviet-to-CONUS trajectories would be completely in the Earth's shadow only when launched during a brief time window on or near the winter solstice. Certain SLBM trajectories had full-shadow launch windows from late fall to early spring. However, trajectories representing those of SS-18's flew very close to the pole, exposing most of their paths to sunlight regardless of launch time or solar latitude. Weighting the trajectories to represent aggregates of a Soviet spike attack, at least 69 percent of the threat was exposed to sunlight for at least 500 seconds on the winter solstice, and at least 95 percent was exposed on the spring/fall equinoxes. These percentages exceed the JCS requirements of a Phase One Strategic Defense System, particularly because of the susceptibility of SS-18 trajectories to sunlight exposure.

CONTENTS

INTRODUCTION

The detection and tracking of ballistic objects is commonly thought of as either a long-wave infrared (LWIR) or radar sensor problem. While the exhaust plume of a burning booster may provide a very bright signature in the short-wave infrared (SWIR), visible, and ultraviolet (UV) wavelengths, a "cold body" in the ballistic or midcourse phase of a trajectory has no distinguishing plume. LWIR sensors can detect the dim warmth of these objects against the cold background of space, but such detectors require elaborate cooling and are quite expensive. Active sensors such as radars are not limited by target temperatures, but have significant power requirements to provide surveillance over large volumes of space.

Visible sensors, in contrast, are relatively inexpensive, comparatively low technology, and do not require elaborate cooling or large quantities of power to operate. They are quite attractive as adjuncts to LWIR systems if the same optics can be shared between both visible and LWIR detector arrays. In this case, the same optics can provide a potential ten- to twentyfold increase in resolution for visible over LWIR due to the diffraction limitation on resolution of λ/D, where λ = wavelength (0.5 μ for visible, 10 μ for LWIR), and D is the aperture diameter of the shared optics.

While LWIR sensors and radars can function without regard to solar illumination, visible sensors are useful only when the targets they are trying to detect do not lie in the Earth's shadow. The portion of a ballistic trajectory exposed to sunlight is governed by many factors including launch and impact points, apogee altitude, time of launch, and solar latitude (time of year). The goal of this paper is to illustrate the geometric conditions under which visible sensors can detect ballistic objects on specific trajectories, and to examine the coverage provided by visible sensors in a strategic defense system against an aggregated threat composed of many trajectories.

MODEL GEOMETRY AND ASSUMPTIONS

The basic geometry model used for this analysis is shown in Figure 1. The Earth was assumed to be spherical with a mean radius of 6370 km. Umbra and penumbra shadows were not included in the calculations; the shadow region is defined as a cylinder behind the Earth whose axis is aligned with the position of the sun in longitude (time of day) and latitude (time of year).

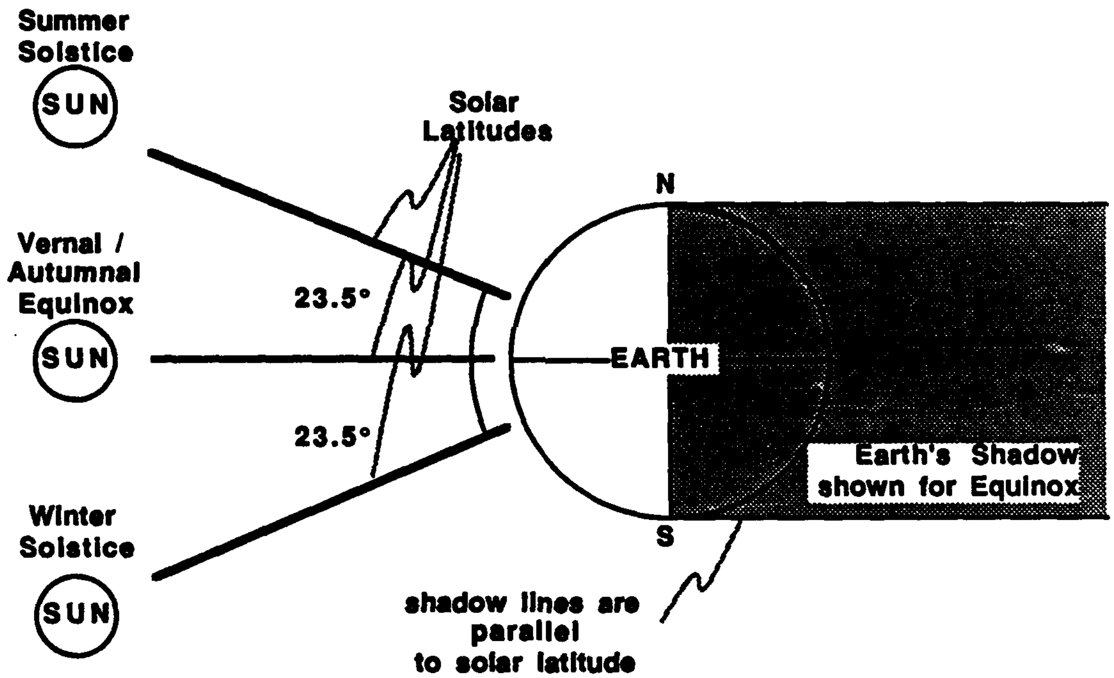

Figure 1: Sun and Earth shadow geometry

For simplicity, the trajectories used in this analysis are all completely ballistic with no modelling of the boost or terminal phases. To compensate approximately for the acceleration in boost phase, the timelines given for each trajectory in this analysis should have the 0 to 100 second segment expanded to 200-300 seconds, depending on the booster type (i.e., end of boost phase and deployment of ballistic objects roughly coincide with 100 seconds as labelled in the figures following). A rotating Earth was used for calculation of the trajectories.

REPRESENTATIVE TRAJECTORIES

The primary variables affecting what fraction of a given trajectory is exposed to sunlight are solar latitude (−23.5° at the winter solstice to +23.5° at the summer solstice), time of launch, apogee altitude, and location of the launch and impact points. Trajectories which come close to the north pole (e.g., SS-18 trajectories from central Soviet Union to central CONUS) are less sensitive to the effects of solar latitude and launch time than trajectories which pass over the lower latitudes (e.g., SLBM trajectories off the east and west coasts of CONUS or the Soviet Union).

In order to understand how these variables affect sunlight exposure of realistic ICBM and SLBM trajectories, nine representative trajectories were selected using CONUS ground targets and aggregated launch sites in the Soviet Union. Table 1 lists relevant information on these trajectories, while Figure 2 shows a polar projection of their paths over the Earth's surface. The labelled markers shown in the figure indicate the positions of ballistic objects on these trajectories 500 seconds after launch.

Table 1. Parameters Defining Representative Trajectories

Traj.	Launch		Impact		# of	% of	
#	Lat	Long	Lat	Long	RVs	Total	Type
1	51.54°N	62.18°E	47.00°N	110.0°W	1520	25.7%	Min. Energy
2	56.07°N	83.96°E	47.00°N	110.0°W	1360	23.0%	Min. Energy
3	57.81°N	42.8°E	38.90°N	77.01°W	560	9.5%	Depressed (75%)
4	57.81°N	42.8°E	41.15°N	96.00°W	560	9.5%	Depressed (75%)
5	57.81°N	42.8°E	34.05°N	118.23°W	560	9.5%	Depressed (75%)
6	51.02°N	116.08°E	41.15°N	96.00°W	500	8.5%	Depressed (75%)
7	51.02°N	116.08°E	34.05°N	118.23°W	500	8.5%	Depressed (75%)
8	55.00°N	170.0°E	34.05°N	118.23°W	220	3.6%	Depressed (75%)
9	70.00°N	0.0°E	38.90°N	77.01°W	128	2.2%	Depressed (75%)
				Total	5908		

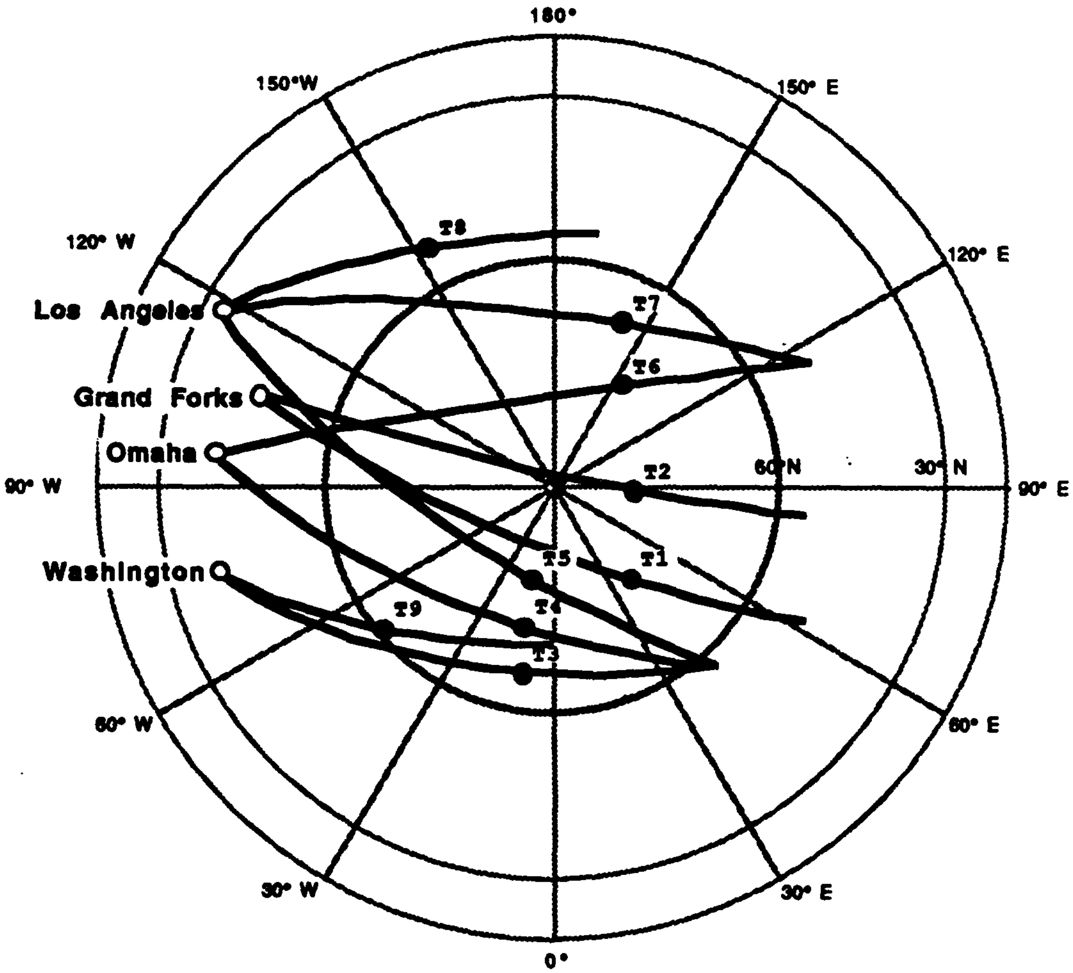

Figure 2. Polar Plot of Representative Trajectories

In Figures 3 through 11 the fraction of each trajectory which lies within the Earth's shadow for flight-time increments of 100 seconds is shown for launch-time increments of two hours and for three solar latitudes. (Shaded boxes indicate when the trajectory is in the Earth's shadow for a particular season.)

summer solstice (+23.5°) ▩

spring/fall equinox (0°) ▩ ■

winter solstice (-23.5°) ▩ ■ ■

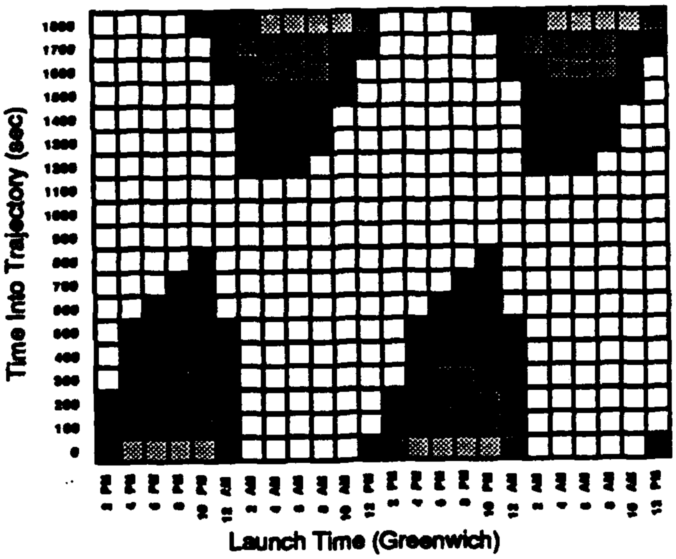

Figure 3. Shadow Plot for Trajectory 1

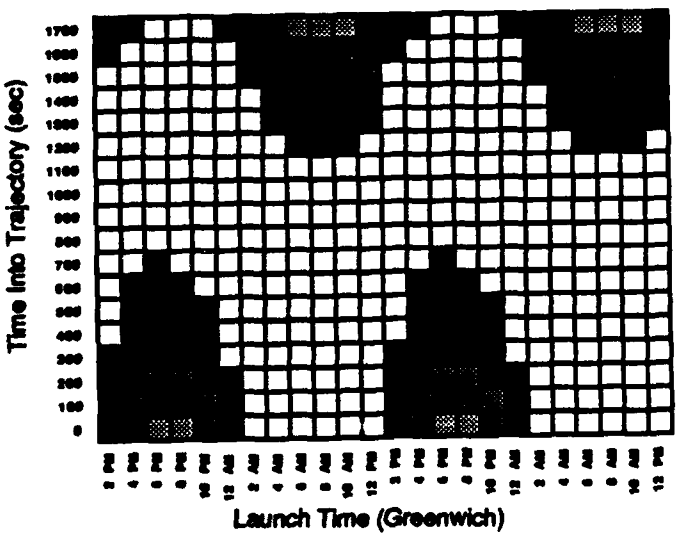

Figure 4. Shadow Plot for Trajectory 2

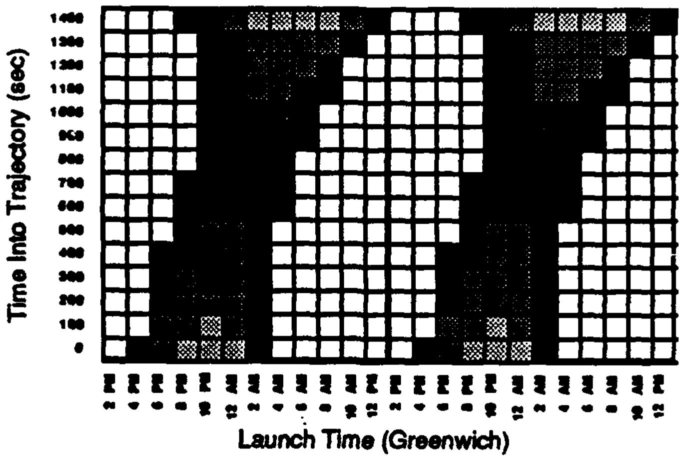

Figure 5. Shadow Plot for Trajectory 3

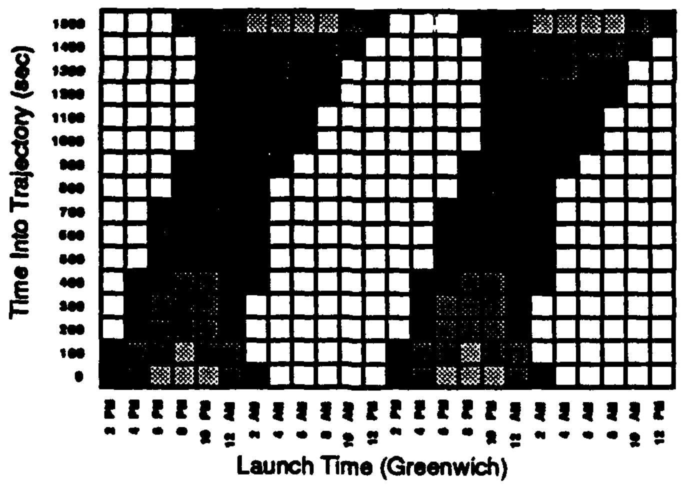

Figure 6. Shadow Plot for Trajectory 4

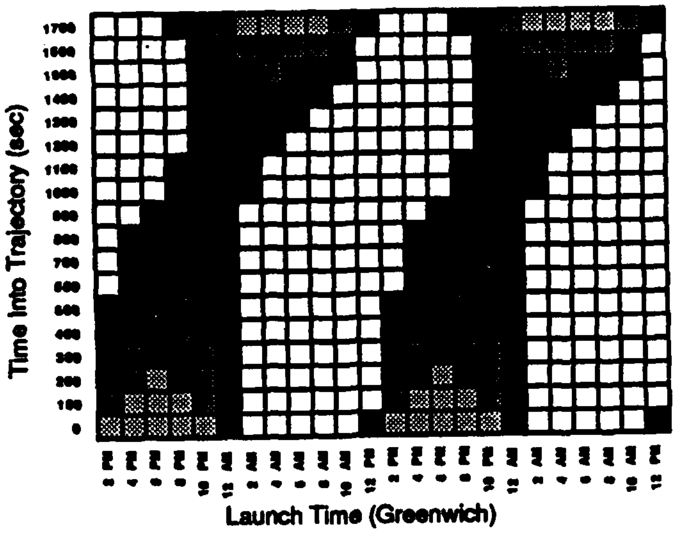

Figure 7. Shadow Plot for Trajectory 5

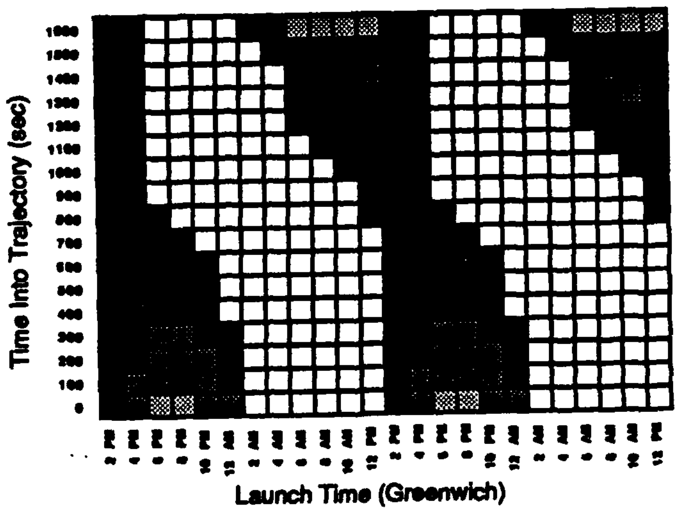

Figure 8. Shadow Plot for Trajectory 6

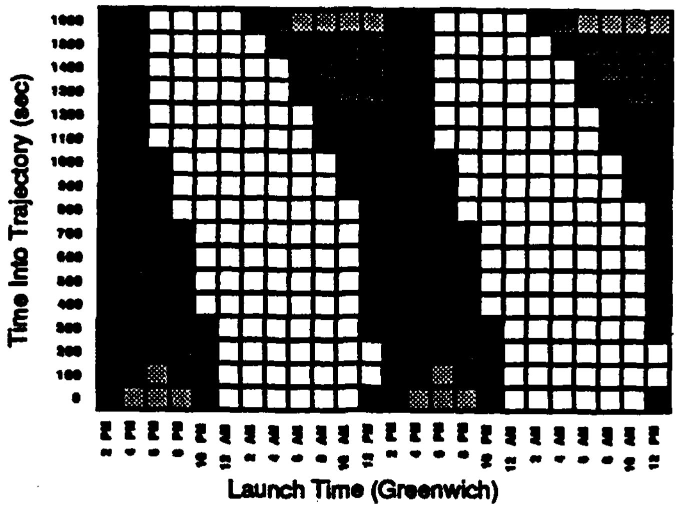

Figure 9. Shadow Plot for Trajectory 7

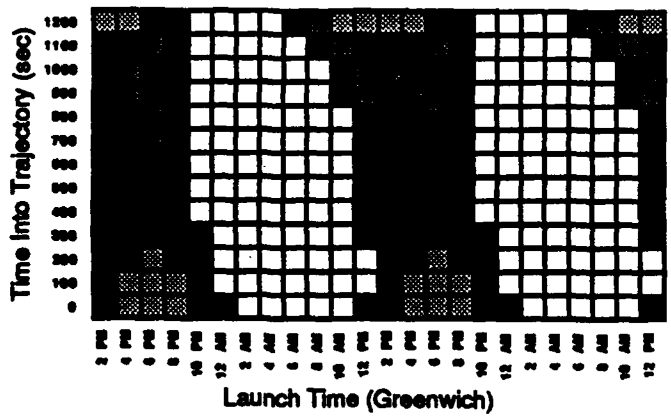

Figure 10. Shadow Plot for Trajectory 8

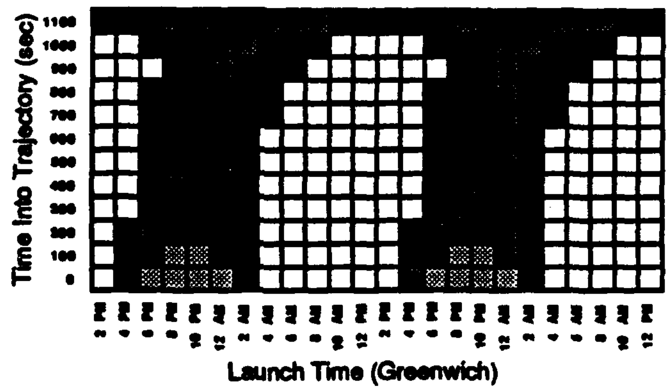

Figure 11. Shadow Plot for Trajectory 9

Several initial observations can be made from these shadow plots:

(1) Trajectories 1 and 2, representing an aggregated SS-18 attack on U.S. ICBM fields, are never completely in the Earth's shadow, even on the winter solstice. Even in the worst case, these trajectories are in the sunlight for at least 900 seconds. This is due to their proximity to the pole and their high apogee altitude (minimum energy).

(2) All other ICBM trajectories (3 through 7) each offer only a six-hour launch window during which the trajectory is completely in the Earth's shadow. However, this only occurs in the deep winter (winter solstice).

(3) The SLBM trajectories (8 and 9) offer full-shadow launch windows between the winter solstice and the equinoxes. This is due to the short range, depressed apogee, and low latitudes of the SLBM trajectories.

(4) Full-shadow launch windows for ICBMs in the eastern Soviet Union correspond with high solar illumination launch windows for ICBMs in the western Soviet Union, and vice versa.

FULL THREAT ANALYSIS

Since full-shadow launch windows for various Soviet launch sites do not coincide, it is obvious that in an all-out simultaneous launch attack from many launch sites to many impact points, some fraction of the total threat will be in the sunlight for some period of time. To examine this issue in further detail, each of the nine trajectories was assigned some number of RVs (see Table 1) so that each would represent a "threat tube", or an aggregate of many trajectories with geographically clustered launch and impact points.

Taking the data represented in Figures 3 through 11, some statistics for a simultaneous launch of these nine threat tubes are shown in Figures 12 and 13. Figure 12 shows the case where a minimum of 500 sec of sunlight illumination is required to provide useful tracking and/or discrimination opportunity to a strategic defense system. Figure 13 shows the case for a minimum requirement of 1000 sec of sunlight illumination.

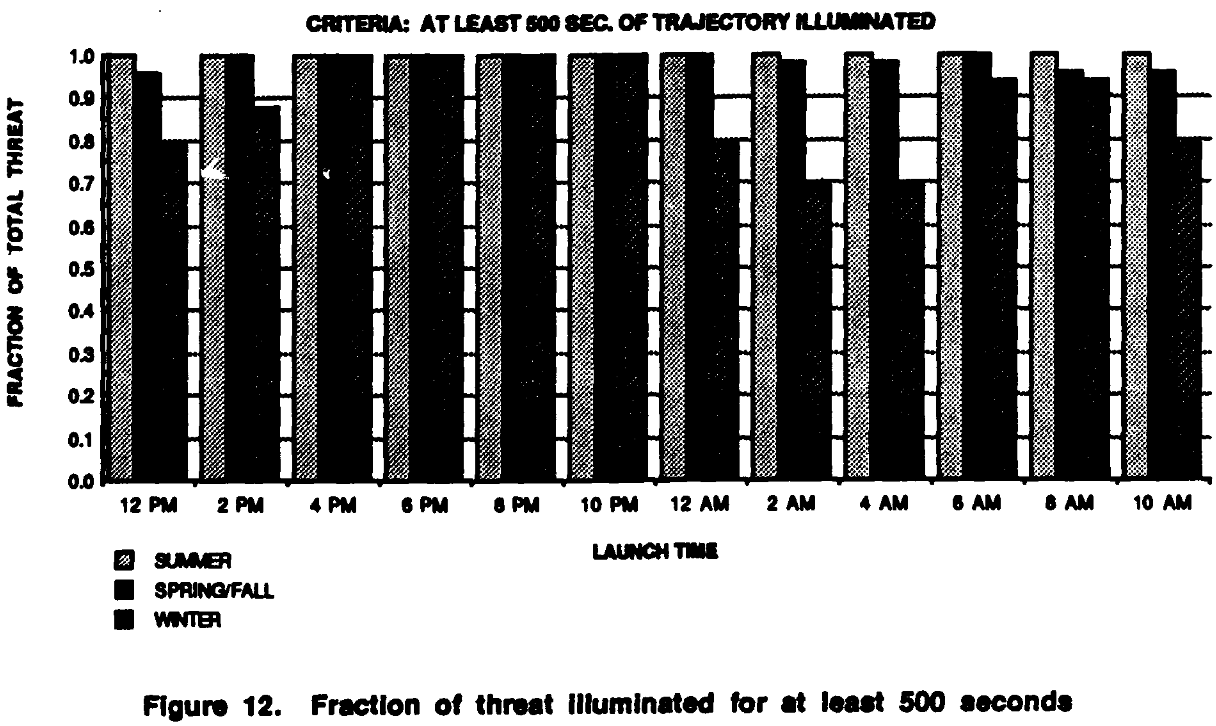

Figure 12. Fraction of threat illuminated for at least 500 seconds

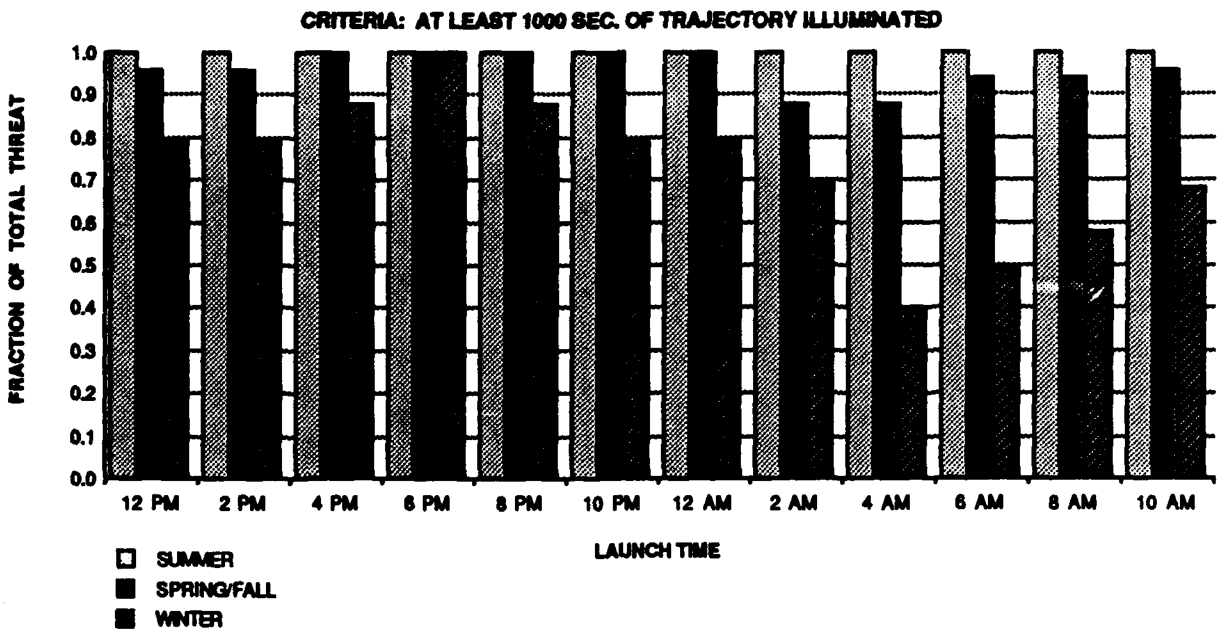

Figure 13. Fraction of threat illuminated for at least 1000 Seconds

In both cases, 100 percent of the threat is visible for the required times on the summer solstice, regardless of launch time. A minimum of about 90 percent is visible at the equinox. Only as the sun approaches the winter solstice does the situation deteriorate. The SLBMs and some of the low-latitude ICBMs do not meet the two criteria as the solar latitude drops through 0° (spring/fall) to –23.5° (winter), particularly for launch times around 4:00 a.m. (Greenwich). Only one of the minimum energy ICBM trajectories (SS-18) did not meet the 1000 sec criteria (illuminated for only 900 seconds) for one launch interval on the winter solstice. Increasing the apogee of the depressed trajectories up to minimum energy results in a few percent increase in the fraction of threat exposed to sunlight.

Figures 14 through 17 show the view from the sun for selected time of year and launch time (only trajectories 1-5, 8, and 9 are shown). The trajectory segments which are visible in these figures are exposed to sunlight. Comparing these views with the shadow plots on the previous pages should give the reader a better understanding of how even semi-polar trajectories are very susceptible to sunlight illumination.

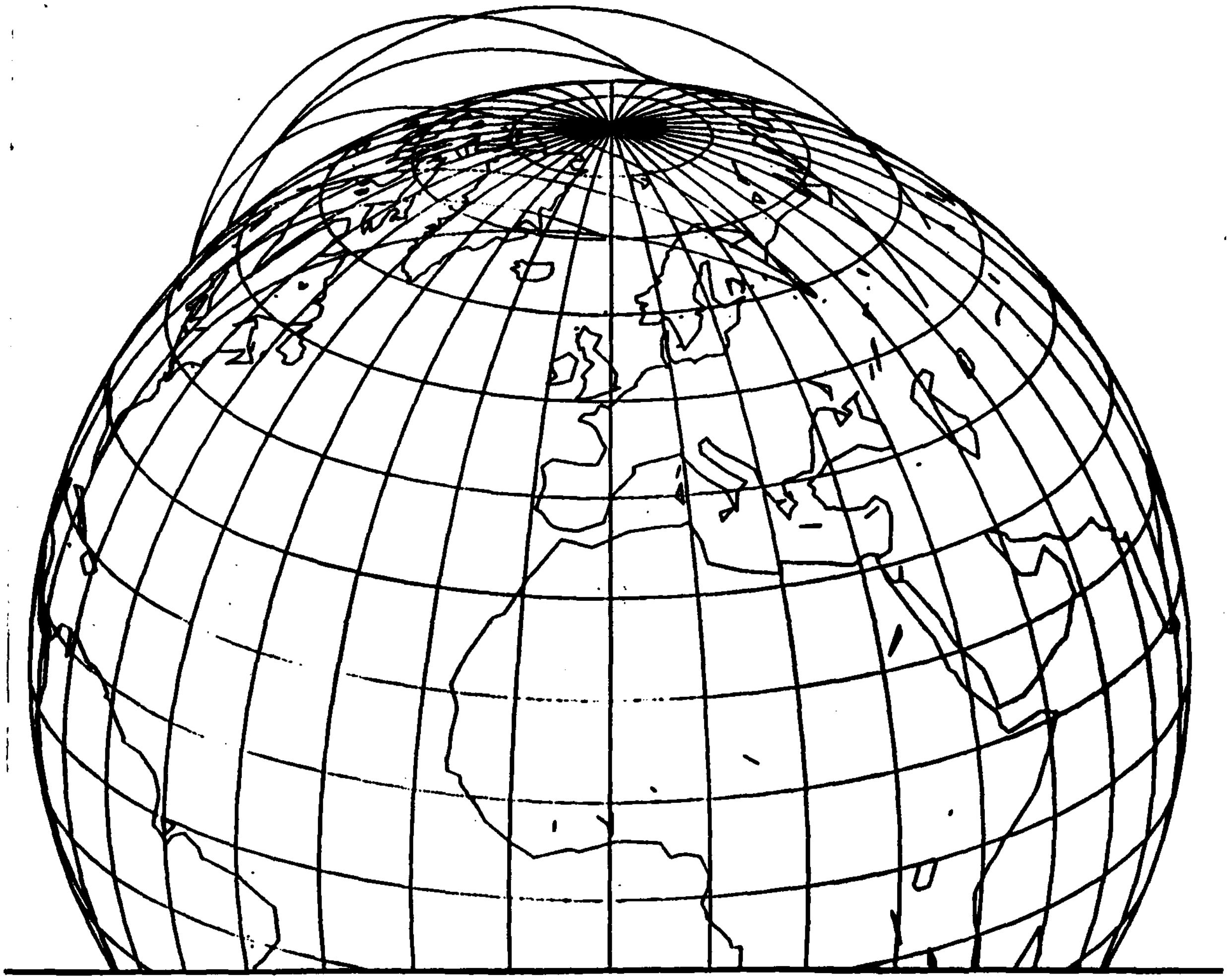

Figure 14. View from Sun at 12 p.m. GMT (launch time) on the Summer Solstice

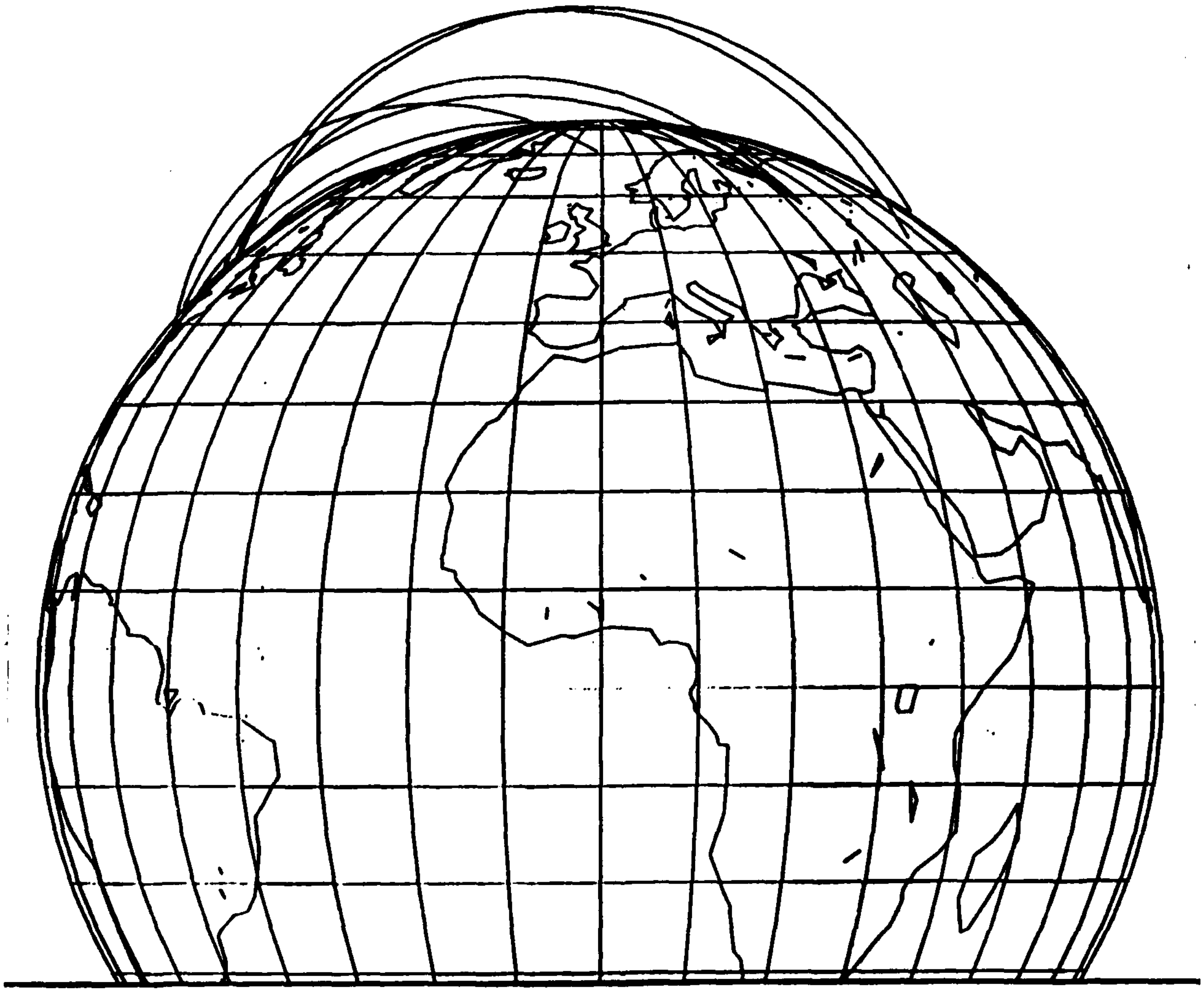

Figure 15. View from Sun at 12 p.m. GMT (launch time) on the Vernal/Autumnal Equinox

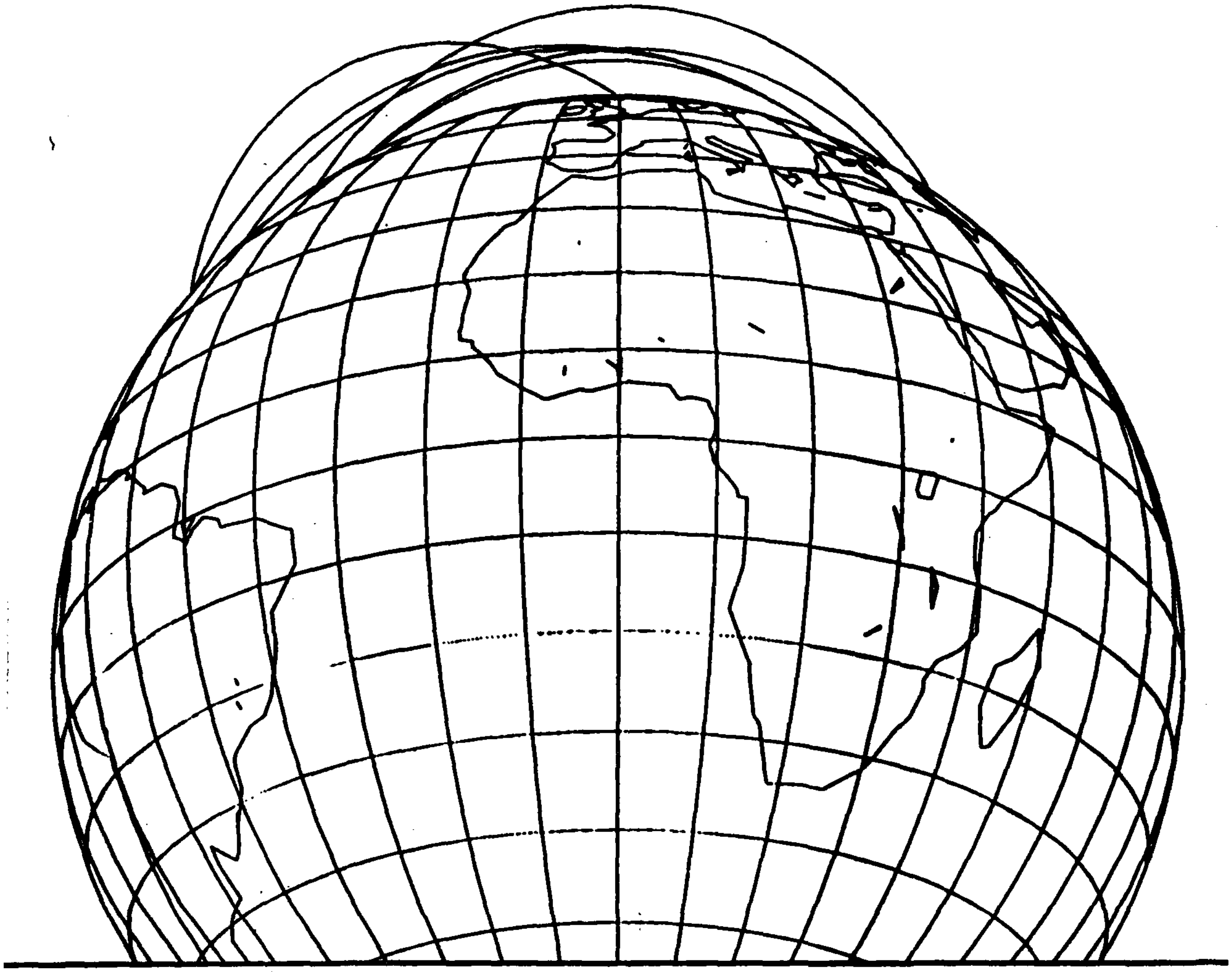

Figure 16. View from Sun at 12 p.m. GMT (launch time) on the Winter Solstice

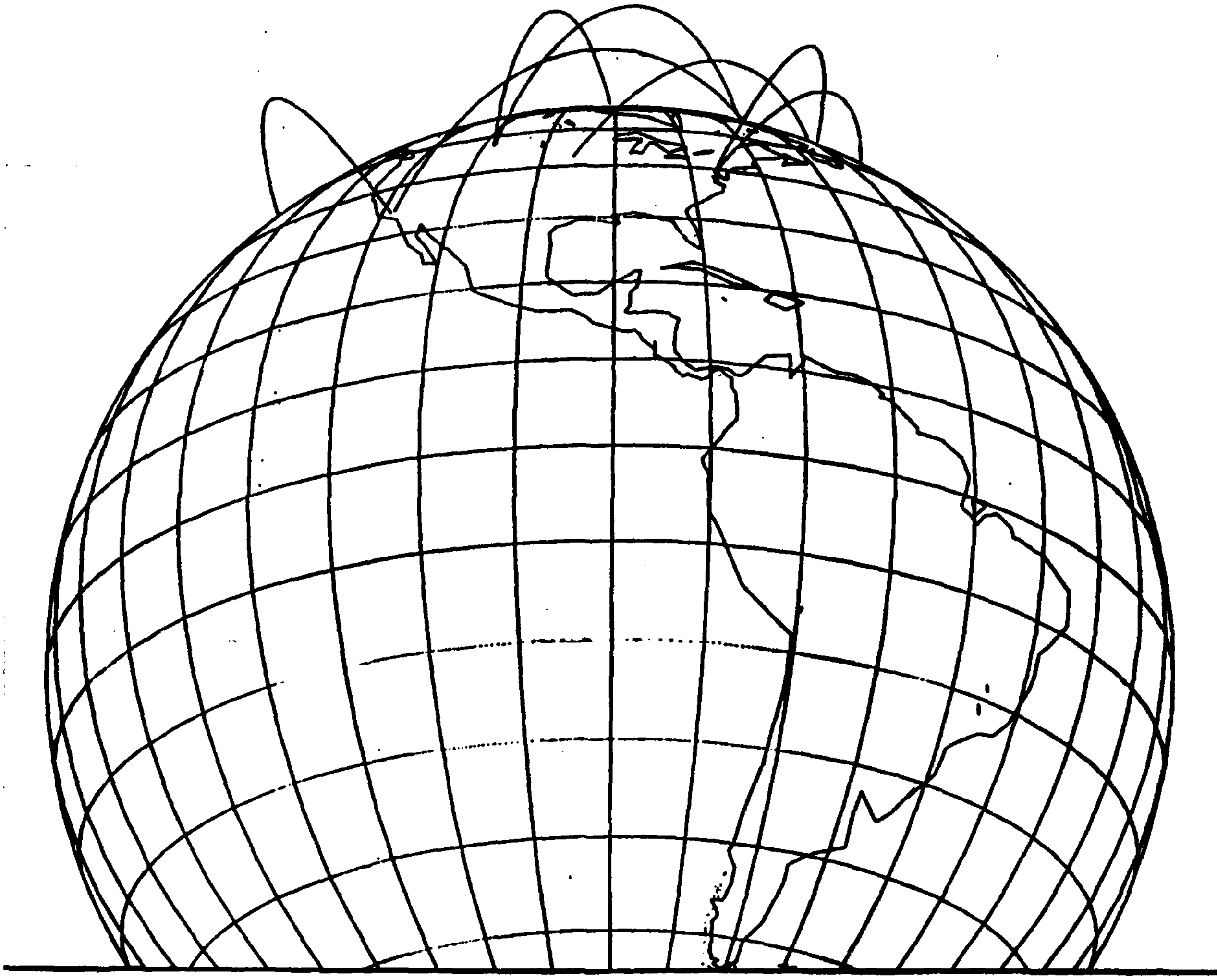

Figure 17. View from Sun at 6 p.m. GMT (launch time) on the Winter Solstice

CONCLUSIONS

Depending on the specific trajectory, launch time, and solar latitude, individual ICBM minimum energy trajectories generally cannot be launched such that the sun does not illuminate at least 900 seconds of their path. There are some extreme cases such as SLBMs and depressed low latitude ICBMs which can remain in total shadow, but only for brief launch windows in the deep winter. Unless two trajectories are following the same general path, these launch windows will not occur at the same time. From the spring through the fall, the trajectories examined spend the majority of their time (at least 75 percent) in sunlight.

For a strategic defense system defending against a massive launch from multiple sites in the Soviet Union to multiple sites in CONUS, the vast majority of the threat will spend a significant period of time (500-1000 seconds) illuminated by the sun. Even worst case scenarios for solar latitude and launch time do not place the majority of the threat in the Earth's shadow.

Although the entire threat examined in this analysis would not always be observable by reflected sunlight, a fraction of the threat exceeding the JCS requirements for a Phase One Strategic Defense System would certainly spend significant time out of the Earth's shadow, particularly for the high-latitude, minimum energy SS-18 trajectories (e.g., trajectories 1 and 2). It should be noted, however, that this analysis addresses only the question of illumination, and not of observability. Although issues regarding aspect angle and surface reflectivity must also be addressed, there appears to be significant potential for using visible sensors as adjuncts to LWIR systems on strategic defense sensor platforms.